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PLATE XXIV

ROBERT MILLFORD MOTHERWELL
1882-1940

THE JOURNAL
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Vol. XXXIV, No. 10 DECEMBER, 1940 WHOLE No 299

ROBERT MILLFORD MOTHERWELL, 1882-1940

By R. J. McDIARMID

(With Plate XXIV)

THE sudden death of Robert Millford Motherwell on September 30, 1940, brought to a close a most active and useful life, not only in his chosen profession of Astronomy, but in other community activities. His popular lectures and talks on astronomy developed among young people much interest in this science. His association with movements both in the church and outside it, made Robert Motherwell a greatly valued citizen for his many services to his fellowmen.

He was born 58 years ago at Millford, Manitoba, son of the late Mr. and Mrs. George Motherwell, the Irish branch of a well known Scottish family. His Scotch-Irish ancestry no doubt accounted for the many fine qualities of character that Mr. Motherwell possessed. A gentleman of the highest integrity, kind and considerate of others, very frank in his convictions and always a loyal and true friend, won for him the admiration and friendship of all with whom he came in contact, and he will be greatly missed by fellow workers in his chosen field of science, and in the field of community service.

His high school education was completed at Perth, Ontario, following which he taught school for nearly three years before going to the University of Toronto. In the fall of 1903 he entered University College, taking the honour course in Mathematics and Physics, graduating in 1907 with degree of B.A., and was awarded the gold medal of the Royal Astronomical Society of Canada. The following year he received his M.A. degree. His interests while at

Varsity gave the background of his later life; a great supporter of the Y.M.C.A. among the students, keen in sports and active in the University College Literary Society, all of which played their part in later years.

Following his graduation he joined the staff of the Dominion Observatory at Ottawa. For a number of years he did micrometric work and carried out investigations on selected visual double stars; also many occultations of the moon were predicted and observed by him. Mr. Motherwell carried out a series of investigations, testing the 8-inch and 6-inch objectives of the photographic doublet, and it was due to these investigations and to recommendations made by him that this instrument proved so accurate in astronomical photography. In connection with the photography of comets Mr. Motherwell proved himself an expert photographer. Halley's comet of 1910 was photographed by him from November 1909 till disappearance late in 1910. Some excellent plates were obtained.

In 1912 Mr. Motherwell did special work at Yerkes Observatory, University of Chicago, working under Professor Parkhurst. His training there had to do with the study of the variation in the brightness of stars by measuring the diameters of the stellar image, slightly out of focus. This method of stellar photometry, known as the extra-focal, was first applied at Ottawa to the study of spectroscopic binary systems in the hope of discovering Algol variables, and later to short period variables.

In 1924 the extra-focal method was superseded by that of measuring the light intensities on the photographic plate, using the thermopile photometer. Short-period variable stars were investigated by this method, but his chief contribution had to do with the international programme of Cepheid variables. The problem of Cepheid variable stars is a most important line of astronomical research. The period of the variation in the brightness of these stars is directly related to their luminosity and it is possible from these relations to determine their distance, hence the astronomer has at his disposal a powerful method for sounding the depths of the universe. This was a co-operative scheme, the principal observatories of the world taking part. During these years he continued to investigate comets and novae by photography.

Astronomy did not claim all Mr. Motherwell's interests. He was a past president and charter member of the Professional Institute of the Civil Service of Canada, also a past president of Ottawa Horticultural Society. He was closely associated with Y.M.C.A. work, and served the United Church on many of its boards. His special interest was in his contacts with the young people, as was shown by his activities in Sunday school work (being superintendent of one of the largest schools in Ottawa at the time of his death) and in boys' camps, especially that of the summer camps. During the summers since 1921, Mr. Motherwell gave popular lectures on astronomy at several boys' and girls' camps in Ontario and Quebec, chief of which was the Ottawa Boys' Camp, Mink Lake, Y.M.C.A. Camp, Golden Lake, Ontario Religious Educational Council Camp, Madoc, Dundas Boys' Work Board, Stormont and Glengarry Boys' Work Board, and in Quebec, camps of a similar character at Kanawana and Magog. It can be said that there are thousands of young Canadians who atribute their interest in the stars to the camp-fire talks Mr. Motherwell so enthusastically gave during his twenty years of activity with boys' work. It was only last summer that the writer met a student of Queen's University, now studying Theology, who said the stars and planets had taken on a new meaning after hearing Mr. Motherwell's talks on the stars. In 1938 he was presented with a gold medal in appreciation of his ten years service to the Boys' Camp at Mink Lake as a lecturer on astronomy.

On June 1st of this year Mr. Motherwell retired on superannuation. Always a great imperialist, his concern was—what can I do to help Britain? He volunteered to go into the gauge-inspection work and his training in precision work made him a very valued official to the Munitions and Supply Board.

In 1912 Mr. Motherwell married Irene, daughter of the late Dr. W. F. King, for many years Canada's Chief Astronomer, and Mrs. King. Besides his widow, three children survive: two sons, William, Science Master Picton Collegiate, Picton, Ontario; Robert, an engineering student at Queen's University; and one daughter, Elizabeth, in the Civil Service, Ottawa.

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Ottawa, Canada.

VISUAL PHOTOMETRY OF VARIABLE STARS

By H. Boyd Brydon

(*Continued from page 417*)

To convert to Julian time first change local standard time into Greenwich Mean Time, G.M.T.,[10] by adding the appropriate number of hours, then turn that into Julian Time. For example in Victoria, B.C., Standard Time is Pacific Standard Time or 120th Meridian time, which is 8h slow of G.M.T. or U.T. Suppose now an observation made at Victoria on 1940 January 15 at 9^h 13^m p.m. is to be recorded in Julian time. We have

	d	h	m
P.S.T. of observation.....	15	21	13
Add for 120° Longitude west.....	..	8	00
	15	29	13
G.M.T., or U.T., of observation.....	16	05	13

which, expressed in decimals[11] of a day, is Jan. 16·217

When in 1925 the astronomical day was changed by one-half day from beginning at noon to beginning at the previous midnight, in order to make it correspond with the civil day, it was considered inadvisable to change the Julian day also. Consequently we enjoy the incongruity of the Julian day starting one-half day *later* than the astronomical and civil days. This confusing difference in time must not be overlooked when converting U.T. into Julian time.[12]

[10]The "Nautical Almanac" uses the term Greenwich Mean Time for the mean time commencing at midnight at Greenwich. The "American Ephemeris" calls this Greenwich Civil Time, G.C.T.,—not to be confused with daylight or summer time, which is never used for astronomical purposes. The term Universal Time, U.T. is however coming increasingly into favour to replace both G.M.T. and G.C.T.

[11]Tables for converting hours, minutes, and seconds of mean time into decimals of a day are given in the "Nautical Almanac," "American Ephemeris," "Norton's Star Atlas," etc.

[12]The Tables of Julian day numbers given in the "Nautical Almanac," "American Ephemeris," R.A.S.C. "Observer's Handbook," etc., state the number of Julian days which have been completed at noon U.T. of date. At 0h on any date therefore the number of the existing Julian day is one-half less than the number which appears for that date in the Tables.

In the present example then we find from Table II of the "Nautical Almanac" that the number of Julian days elapsed at noon on January 0, 1940 (which is December 31 noon, 1939) was 2,429,629 or on

January 0, 0h was	2,429,628·5
Adding the January date of the observation	16·217
we have	2,429,644·717

as the Julian date of the observation which is usually reported as 9,644·717.

This apparently unnecessary and involved transformation is neither. By reducing all observations to a single system of counting time, which extends back by the way to B.C. 4713, a quick, simple, accurate way of comparing the dates of astronomical occurrences is available. Computation of the periods of variable stars and such phenomena as the minima of Algol (see the R.A.S.C. "Handbook") would be exceedingly onerous without it. It was introduced into variable star work by E. C. Pickering about fifty years ago and has been adopted everywhere.

Before leaving the matter of records be it remembered that records are made not so much for the convenience of the maker as for the use of one to whom they may be of value subsequently. Therefore they must be made so that they will be completely clear to an intelligent stranger without further explanation.

The record should show by notes made at the time of observation, not from memory later, the conditions under which the observations were made; the presence or absence of haze, light cloud, moonlight, twilight, aurora, etc., brightness or darkness of the sky and the magnification used.

So far as is known, stellar photometry begins with Hipparchus, who about B.C. 110 formed a catalogue of about 1000 stars and arranged them in six orders of brightness or "magnitude." In magnitude *one* were put the conspicuously bright stars. Magnitude *two* contained the next brightest and so on down to magnitude *six*, which contained the faintest stars he could see in the clear Mediterranean skies. The relationship of one magnitude to another, however, remained very inexact for nearly two thousand years when Sir John Herschel concluded from many careful measurements that a first magnitude star is about 100 times as bright as a star

of the sixth magnitude, a ratio which has been amply confirmed and is now universally adopted.

What exactly do we mean by the "brightness" of a star? We mean the total amount of light that the eye perceives to come from the star. If twice as much light appears to come from one star as from another we say the first star is twice as bright as the second. Notice in these sentences that the emphasis is on the appearance of brightness. We cannot compare the intrinsic brightness of the stars themselves; we can only compare the impressions of their brightness that our eyes enable us to form. That is, we compare the sensation, not the cause which produces the sensation.

Now it happens that a sensation is not directly proportional to its cause. Suppose we have two globes, one containing four candles and the other containing two candles, all burning brightly. One globe of course will look brighter than the other. If now we add one candle to each of the globes the increase in brightness of the two-candle group will appear to be greater than the increase in brightness of the four-candle group although the increases actually are identical. The same added quantity of light produces less effect in the case of the four candles than it does in the case of the two candles.

To make the gain in brightness of the four-candle group appear equal to the gain in brightness of the two-candle group we must add two candles to it whereas we added only one to the two-candle group. We must increase both not by the same amount but in the same proportion.

Observe that this is quite a different matter from the inverse square law of illumination; that the illumination of a surface varies inversely as the square of its distance from the light-source. We are now discussing not the appearance of illuminated surfaces but the intensities, that is to say, the brightnesses of lights themselves and we compare those brightnesses by comparing the sensations which we experience as caused by them.

Putting this in general terms we have the remarkable psychological law of Fechner. It may be stated thus:—As a stimulus S increases geometrically, the resulting sensation F increases arithmetically.

Expressed mathematically we put

$$S = C^F, \text{ or } \log S = F \log C,$$

where C is a constant to be determined experimentally.

Another illustration of the working of this law is given by Fig. 3 in which are shown two rows of white discs. Examine this figure under a strong light from a distance of not less than 6 ft. Seen from this distance all the discs may be considered as being practically point sources of light. Artificial stars in fact.

When the discs are compared with the others in the same row, those in the top row look nearly equally bright until close to the right hand end where they fall off rapidly whereas those in the bottom row appear to diminish regularly and equally from disc to disc.

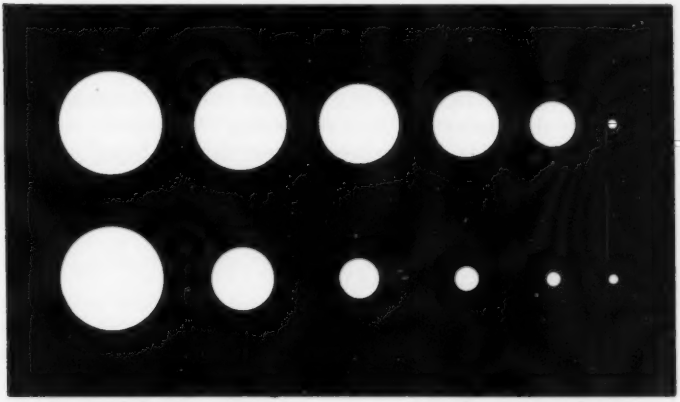


Fig. 3.—Arithmetic and geometric variation of brightness.

In both rows the brightest disc is one hundred times as bright as the faintest, but in the top row the brightness decreases arithmetically by a constant quantity while in the bottom row it decreases geometrically, each disc being fainter than the preceding by a constant multiplier, the same as has been found by observation to exist between stellar magnitudes.

As there is no intrinsic standard of brightness for a star its brightness can be determined only indirectly, by comparing the sensation it occasions with that produced by another star; by comparing their magnitudes. Thus if B_1 and B_2 are the brightnesses

of two stars and M_1 and M_2 their magnitude numbers, we have from Fechner's law

$$B_1 = C^{M_1} \text{ and } B_2 = C^{M_2}$$

Putting Δm for the difference between their magnitude numbers and dividing one by the other we have

$$B_1/B_2 = C^{\Delta m}$$

and, inserting the values given above, namely $B_1/B_2 = 100$ and $\Delta m = 5$, we have $100 = C^5$ or $5 \log C = \log 100 = 2{\cdot}000$, whence $\log C = 0{\cdot}4000$ and $C = 2{\cdot}512$.

Thus one star a is *defined* to be one magnitude brighter than another star b when its light is 2·512 times as bright, this ratio being originally based upon observation but finally *adopted*, so that a difference of 5 magnitudes shall correspond to a light ratio of 100 to 1.

Measuring the brightness of a variable star then is not making an absolute determination, it is comparing the variable with one or more non-variable stars whose magnitudes are based upon the above ratio.[13]

Some illustrations of the important equation given above are worth study:

A. At minimum, Mira, o Ceti, is about 9·6 mag. How much brighter is it when it reaches a maximum of 4·0 mag.?

Here $\Delta m = 9{\cdot}6 - 4{\cdot}0 = 5{\cdot}6$ and we have

$$\log B_{\text{max.}}/\log B_{\text{min.}} = 5{\cdot}6 \log 2{\cdot}512$$
$$= 5{\cdot}6 \times 0{\cdot}4 = 2{\cdot}24$$

whence $B_{\text{max.}}/B_{\text{min.}} = 174$ times (brighter).

Mira occasionally rises to a maximum of 3·0 mag. How much brighter than at minimum is it then?

Here $(4{\cdot}0 - 3{\cdot}0)\ 2{\cdot}512 = 2{\cdot}512$ times brighter than when it reaches magnitude 4 or $174 \times 2{\cdot}5 = 437$ times brighter than at minimum.

B. Nova Persei 1901 was 25,000 times brighter at maximum than before the outburst. How many magnitudes did it increase?

$$\Delta m = 2{\cdot}5 \log 25{,}000$$
$$= 2{\cdot}5 \times 4{\cdot}4 = 11 \text{ magnitudes.}$$

C. The magnitudes of the two components of the beautiful double star γ Leonis are 2·6 and 3·8. What is their combined magnitude?

Here we make use of an artifice. We first find the brightness, $B_{2{\cdot}6}$ and $B_{3{\cdot}8}$ of each component with respect to the brightness B_0 of a zero magnitude star, then compute their combined magnitude similarly thus:—

$$B_0/B_{2{\cdot}6} = (2{\cdot}512)^{2{\cdot}6} = 10{\cdot}97$$

whence $B_{2{\cdot}6}$ is $\dfrac{1}{10{\cdot}97}$ as bright as B_0

$$B_0/B_{3\cdot8} = (2\cdot512)^{3\cdot8} = 33\cdot12$$

whence $B_{3\cdot8}$ is $\frac{1}{33\cdot12}$ as bright as B_0

Let x be their combined brightness

$$\text{then } x = \frac{1}{10\cdot97} + \frac{1}{33\cdot12} = 0\cdot0911 + 0\cdot0302$$
$$= 0\cdot1213 \text{ as bright as } B_0$$

$$\text{whence } B_0 = \frac{1}{0\cdot1213} = 8\cdot745\ x$$

Then $(2\cdot512)^x = 8\cdot745$
Taking logarithms we have $0.4\ x = 0\cdot942$
whence $x = 2\cdot35$.

D. Show that the combined magnitude of any two equally bright stars is 0·75 mag. less than either.

Let x equal the brightness of the two stars combined; then,

$$(2.512)^x = 2$$

taking logarithms
$$0.4\ x = \log 2 = 0\cdot301$$
$$x = 0\cdot75.$$

As the eye is the court of last resort, no matter what equipment may be brought to its aid, it is appropriate to consider its peculiarities, that we may recognize its limitations as a photometer and endeavour to avoid errors they might cause. In preparing this description I have drawn largely by his kind permission upon the presidential address of Dr. W. H. Steavenson, F.R.A.S., before the British Astronomical Association in 1929[14] as well as from other sources.

The eye may be conveniently compared with the photographic camera. The body of the camera is represented by the eyeball, a nearly spherical chamber about an inch in diameter with a tough white wall called the *sclerotic coat*, part of which we see as the "white of the eye." The sclerotic coat is lined with a closely packed layer of dark pigment cells called the *choroid* which serves

[13]The term "absolute" magnitude is thus seen to be an unfortunate piece of nomenclature. There is nothing "absolute" about it. It means simply the relative brightness the stars would appear to have were they all at the same distance from us—10 par secs, 32·6 light years. "Standard" magnitude would be more appropriate.

[14]*J.B.A.A.*, v. 39, p. 4. Dr. Steavenson's address and that of Mr. F. J. Sellars, M.I.M.E., *J.B.A.A.*, v. 40, p. 1, which followed it form a valuable discussion of seeing and the telescope.

the purpose of the blacking of the inside of the camera. At the front of the eye the choroid forms the expanding and contracting diaphragm we know as the *iris*, surrounding the black aperture of the *pupil*. The principal use of the iris is to aid in regulating the intensity of the light reaching the *retina*, the delicate, light-sensitive film forming the innermost coat of the eyeball, on which is focussed the image formed by the optical system of the eye.

The retina is composed of about 105 millions of nerve endings branching from the optic nerve. They stand close together like the pile on velvet and have two kinds of ends; rod-like and cone-like. In the peripheral areas of the retina the rod-endings outnumber the cone-endings many times but the cones increase proportionally towards the centre until at the slight depression at the inner end of the optical axis called the *macula lutea* or yellow spot, about 2 mm. in diameter, the cones very greatly outnumber the rods, while at its centre, the *fovea centralis*, where the cones number some 16,000 per square mm. there are no rods.

This tiny spot, the fovea, about 0·5 mm. in diameter, is the area of sharpest definition. The controlling muscles involuntarily move the eye with great rapidity so that the several parts of an image may fall successively on the fovea for detailed examination.

Except in the yellow spot, these nerve endings are bathed continually in a bluish liquid called the *visual purple* which is bleached by the action of light. In some way not yet understood the bleaching of the visual purple aids in passing on the image to that portion of the brain which has to do with seeing, the *occipital cortex*. Different colours bleach the visual purple at different rates; green most rapidly, next yellow and blue, while the bleaching effect of red is but slight.

The rate of bleaching appears to have a controlling effect on the time required to perceive a coloured light, which is of particular importance to the observer of variable stars. Thus W. W. Coblentz remarks:[15] "When the eye is suddenly exposed to lights of different colours the growth of visual sensation is more rapid for blue than for red. . . . For low intensities a long time is required for the visual impression to attain its maximum value." The oft repeated advice in observing red stars to take a prolonged look at them appears justified.

[15] "Photoelectric Cells and the Eye," *Jour. Physiol. Optics*, v. 1, 1920.

In the perception of colour the cones play an important part, but the details of the process are far from being agreed upon by investigators. It may well be, as Troland[16] has suggested, that the seat of colour perception is in the occipital cortex itself and functions by the frequency of the impulses which reach it along the optic nerve, chiefly at least from the cones.

The whole problem of vision, especially of colour vision, is far from solved. Although actively disputed by such investigators as F. Allen, Duke-Elder and others,[17] the view most generally accepted to-day seems to be as follows: The rods and cones have different functions. The rods are concerned with the general perception of light. They see form but not colour and can distinguish small differences of luminosity far below the threshold at which the cones begin to perceive colour. Between these two thresholds the eye is said to have "dark adaptation"; vision is colourless, defined only by shades of grey and the cones are practically idle. Above the second threshold the eye is in the state of "light adaptation," the cones function and colour is perceived.

If these views be correct they have an important bearing on the visibility of stars. Hassenstein[18] considers that on an average clear moonless night the actual condition of adaptation of the normal eye is approximately midway between these thresholds and that in this state and using both eyes (p. 537) without optical aid, the lower limit of visibility for cone vision is from 3·5 mag. to 4·0 mag. while for extra foveal or rod vision it is about 5·6 mag. to 6·0 mag. However these limits depend upon the atmospheric conditions common to the place of observation. There are numerous instances of 7th magnitude stars being seen with the naked eye.[19]

The area of the retina which is sensitive to light and colour is neither symmetrical about the fovea nor uniformly acute. For

[16]L. T. Troland, "The Enigma of Colour Vision", *Jour. Phy. Opt.*, 1920, p. 317.

[17]See Duke-Elder's "Recent advances in Opthalmology" and papers by Dr. F. Allen.

[18]*Hdbh. d. Astrop.*, v. II/2, p. 533.

[19]The literature on the subject of colour vision is very extensive. Papers appear frequently in such periodicals as *Phil. Mag.*, *Jour. Opt. Soc. Am.*, *Psychol. Rev.*, *Jour. Exper. Phys.*, *Jour. Physiol. Opt.*, etc.

white light the angular extension from the fovea is found to be about as follows:

TABLE IV

NORMAL VISUAL ANGLES

Direction from Fovea	Degrees
Vertically upward	45-50
" downward	60-70
Horizontally inward	50-60
" outward	80-90

For coloured light, except green, the areas are roughly the same as these for light of normal intensity but become progressively smaller as the light grows fainter. Areas sensitive to green light are only about one-half as large as those sensitive to red, yellow and blue, but the relative sizes of these areas differ with different individuals.

The eye tells us three things regarding external objects: their size and shape, their luminosity or brightness and their colour. In the observation of variable stars the perception of luminosity and colour is of major importance.

Although the eye can adapt itself to a range of brightness of several millions to one, time is required for the process. As between inside and outside the house on a fine day (a range of about 1 to 100) adaptation is practically complete in a few seconds; but between daylight and darkness (a range of about 1,000,000 to 1) from one to two hours is required for the process of adaptation to be complete. After nightfall, unless the eye has been fatigued by reading in a bright light, adaptation is sufficiently advanced after 20 minutes in complete darkness for observations to be made on faint objects, but within that period as the sensitivity is changing rapidly estimates of brightness are subject to large errors. Red light having the least bleaching effect on the visual purple is preferable when examining charts and making notes. Many observers work in complete darkness and keep the "telescope eye" closed when making notes, to preserve it in the condition of maximum sensitivity.

Since the rods of the dark adapted eye see only in tones of grey, ability to perceive faint stars depends very much upon the degree of contrast between the brightness of the background and the star.

In the telescope contrast can be increased by increasing the magnification. The brightness of the stellar image is not changed but the field is made darker. For instance, with a power of 40 to the inch the field will be only one hundredth as bright as with 4 to the inch, with which it will appear nearly as bright as the sky does to the naked eye. Nevertheless it is inadvisable to change the magnification used for any particular star as the difference of contrast resulting may affect the relative appearance of the variable and the comparison stars.

Occasionally the greater sensitivity of the outer parts of the retina compared with the macula lutea can be used to advantage in observing as it allows objects sometimes fainter by two magnitudes to be perceived. It is accomplished by not looking directly at the object. Ability to see objects "out of the corner of the eye" requires practice. It is helped by lengthening the focus slightly but the star is never sharply defined. It is of some advantage when observing such objects as planetary nebulae but should be used with care in photometric work because the practical impossibility of insuring that the two star images shall fall on equally sensitive parts of the retina makes unreliable all observations so made.

In variable star observation however, the power to see very faint objects is of less importance than ability to distinguish slight differences in brightness, the basis of all visual photometry. Differences as small as one per cent. have been distinguished under careful laboratory conditions but in the observation of variable stars the least perceptible difference is about ten times as large or about 0·1 mag., and is slightly higher for bright stars than for faint ones.

We have said that the peripheral regions of the retina are more sensitive to faint light than is the fovea but the sensitivity is not symmetrical. The upper half of the retina for example is more sensitive than the lower half and the outside half more than that towards the nose.

The effect of this asymmetry on stellar photometry is discussed in a paper by A. W. Roberts.[20] It is pointed out that the error

[20] *M.N.*, v. 57, p. 473, April 1897. An investigation concerning the position error affecting Eye Estimates of Star Magnitudes.

which arises from the common fault of observers of over-estimating the brightness of the lower star in any field frequently amounts to nearly a whole magnitude. Furthermore the error is not constant but varies with the relative position of the variable and its surrounding comparison stars and for any two stars depends upon the cosine of the angle, "the position angle," between the line joining the stars and the vertical line through the centre of the field which changes with the hour-angle of the stars.

The effect consequently is to produce an apparent periodic variation in the light of a star that is but the result of lack of symmetry in the sensitivity of the retina. From his examination of the matter Roberts concludes:

1. The error due to relative position is systematic in its nature.
2. It produces its maximum effect when the position angle is 32°.
3. It affects all magnitudes equally.

As results similar in general have been found by other observers also, there seems little room for doubt that the cause of the error is unequal sensitivity of the retina.

Position angle errors may be avoided by two precautions: First, the line joining the eyes must be kept parallel to the line joining the stars. Second, two observations must be made for each comparison, the positions of the right and left eyes being reversed relatively to the stars. The mean result of the two values will be free from position error as by reversal the brightness of the star which was over-estimated in the first position will be under-estimated in the second. It is of value to test the importance of this suggestion by actual observation.

The most satisfactory means of accomplishing this reversal of the eyes is by means of a diagonal eyepiece. By setting the prism at right angles to the meridian, the necessity of looking upwards with the consequent strain on the neck muscles is avoided. The head is always comfortably inclined except in the unusual case of star and telescope being both on the same side of the pier.[21] Many observers recommend silvering or aluminizing the reflecting face of the prism to prevent loss of light from dirt or moisture adhering to it.

Failing a diagonal eyepiece it is possible to use a terrestrial

[21] *H.A.*, v. 18, p. 32. Parkhurst.

eyepiece for one position but the reflection from the additional air-glass surfaces of the erecting lenses will introduce an error which may amount to 8 per cent. Another method is the use of a concave (Galilean) eye lens; the loss by reflection will be reduced but as Bell[22] points out, it must be used with great caution as the field is generally small and the illumination falls off rapidly from centre to periphery.

As it has been found by Coblentz[23] and others that in general both eyes are equally sensitive to within one to three per cent., the error may be reduced if not eliminated by observing first with one eye and then with the other, but the eyes should be carefully checked by means of tests with artificial stars before accepting the truth of this general statement in an individual case.*

(*To be continued*)

[22]"The Telescope," p. 150.

[23]U.S. Bur. Stds. *Sci. paper* 303.

*It is hoped to present the results of such tests in a future communication.

A NEW METHOD FOR THE PHOTOGRAPHIC OBSERVATION OF DOUBLE STARS

By F. Henroteau

First Communication

THE method described here is based upon the latest improvements in electro-optics. It permits the photography of double or multiple stars only when that part of the terrestrial atmosphere traversed by the light of these stars is absolutely calm, that is, when the seeing is perfect. As soon as this condition ceases, even to a slight extent, the double star immediately ceases to be photographed and then when the atmosphere once more has become calm the action on the photographic plate starts over again.

The method, as can be gathered from the following description, also causes the exposure to be stopped immediately as soon as the image of the primary star is slightly displaced from the position it should normally occupy, by reason of variations in right ascension or in declination. This being the case and one being certain to secure perfect photographic images, these images are analyzed by means of a thermoelectric or photoelectric slit-photometer, in order to obtain photogrammetric curves, from which accurate position angles and angular distances can be derived.

It is known that even when the seeing is only relatively good, there are always short intervals of time when the seeing is perfect. Witness, for instance, the beautiful photographic observations of Mars which are made at the Lowell Observatory in Arizona. About one hundred successive exposures of Mars, of about three minutes each, are taken on the same plate; most of the photographs obtained show absolutely no detail and look like uniformly gray discs, but two or three of them will be absolutely clear, revealing minute details of the planet's surface.[1] Evidently, during the three minutes' exposure necessary to obtain these clear photographs, the terrestrial atmosphere traversed by the light of Mars has been perfectly calm. It is thus possible that in certain privileged regions of the earth, and perhaps in many regions, there are short intervals of time when the

atmosphere traversed by the light of a star is perfectly calm. When this happens, the image of a star formed in the focal plane of the object glass of a good telescope is composed of a small central disc, which we may call the false stellar image, surrounded by alternately dark and bright but fainter and fainter rings. As soon as the atmosphere ceases, even a little, to be calm, one sees the central disc, either moving rapidly to-and-fro about a mean position, or becoming wider and more diffuse, decreasing in brightness over the same unit area. Thus, if one manages to have the central disc of the star-image coming over a small hole, the diameter of which is equal to the diameter of this false stellar image when the atmosphere is perfectly calm, all the light of this false stellar image will go through the hole if the atmosphere is really perfectly calm; but if this calm is not perfect, on account, either of the expansion of this false stellar image, or of its jumping off the hole, far less starlight will go through the hole.

If, back of the hole, there is a photoelectric cell, in preference a modern high-vacuum cell with an electron multiplier which is perhaps a million or more times more sensitive than an ordinary cell, this cell will receive the greatest amount of the starlight when the atmosphere is perfectly calm, that is, under the very best seeing conditions. As soon as the quietness of the atmosphere is interrupted, the cell will receive less light.

The principle of the method is now based on the fact that the photoelectric cell causes an electro-optic shutter to be open when the maximum starlight strikes the cell, and causes also this shutter to be immediately and completely closed as soon as a little less than the maximum starlight strikes the cell.

The operating of the device will be better understood by reference to figure 1 and by the following description:

Let A be a photographic telescope, B its object glass and C an opaque screen covering the central part of this object glass. There is a double purpose in using this screen C; it is known that by hiding the central part of the object glass in order to leave an outside ring of it to be traversed by the starlight, this almost doubles the separating power of the telescope, and this explains the first purpose in using screen C. The second purpose in using it is to place the photoelectric

plate G in the shadow cone of the star in order that the light beams of this star may be reflected upon G by the mirror T.

E is a half-silvered mirror placed in such a way that the image of a star can be focussed on the small hole L in the opaque plate K and can also be focussed on the photoelectric plate G which is in the internal vacuum of a modern electronic microscope F.

The small eyepiece S, having a fairly high power, is used to see

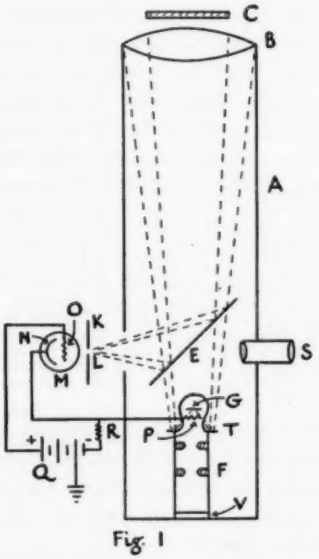


Fig. 1

Fig. 1—Proposed photoelectric addition to a photographic telescope for the purpose of observing close double stars.

the star image on the edge of L. The size of L is equal to the size of the false stellar image when the atmosphere is completely calm, i.e., when the seeing is perfect.

If the components of the double star which is to be photographed are well separated it is only necessary to maintain one of these components, for instance the primary, over the hole L. If the component

images are partially overlapping, the excess luminosity on the edge of the hole L should always be maintained on the same side of this hole L.

The photoelectric plate G (caesium-oxide-silver) which is connected to the negative pole of a battery (not represented on the figure), receives the focal image of the double star. The various points of this plate, which are struck by the light of this image, all omit electrons in proportion to the amount of light received, and these electrons going through the electronic microscope F at a very high speed, cause an enlarged image (indeed very enlarged) of the double star to be formed on the photographic plate V.

Back of the hole L is a photoelectric cell M, the cathode N of which receives all that part of the starlight which passes through the hole L. The anode O of the cell M is connected to the positive pole of a battery Q. The cathode N is connected to the negative pole of the same battery Q through an appropriate resistance R; it is also connected to the grid P which is placed before G. One pole of the battery Q is grounded in order, when the cell M is in the dark, or even struck by an amount of starlight very slightly inferior to the maximum starlight it can receive, to maintain a negative potential on the grid P, large enough to block all the electrons from G which would tend to go through the electronic microscope F.

The power of the cell M and the ohmic resistance R are so adjusted that when the starlight falling on N is maximum, all the electrons emitted by G go through the electronic microscope F to form an image on V, and that for an amount of starlight falling on N which is only very slightly below this maximum, the electrons shooting out of G are all prevented from going through F, so that no image of the star can be formed on V.

The whole device can thus be adjusted in such a way that it is only when the terrestrial atmosphere is perfectly calm, that is, when the stellar image on the hole L has nearly the sharpest definition, that the grid F will allow all the electrons emitted by G to pass through F and form an image of the double or multiple star on V.

P can thus be considered as an electro-optic shutter which is open when the image on L is not only sharp but also well centred; this

shutter closes completely and almost instantaneously as soon as this image on L is very slightly disturbed.

A succession of exposures of extremely sharp images can thus be obtained on plate V; the length of effective exposure could be measured, for instance, by using a recording galvanometer and by measuring the total length of time during which the recorded curve indicates a maximum deflection as produced by the photoelectric current passing through M.

It is to be noted that the use of the electronic microscope is of great value. Outside of the fact that it provides for an efficient electro-optic shutter P to be used, it must be remarked that it offers extraordinary possibilities for enlargement and for definition.

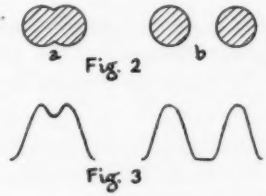
For example, if it is considered that the actual diameters of false stellar images are very small, being about one hundred microns for average telescopes and about four or five microns for very large telescopes such as the two-hundred-inch in California, it should be possible to enlarge these images considerably by means of a sort of eyepiece which would give real images to be photographed.

The electronic microscope is the proper sort of instrument to obtain such enlargements; it is known, indeed, that the German physicists Ruska and von Borries as well as the Canadian physicists Hillier and Prebus, working with Professor Burton of the University of Toronto, have constructed electronic microscopes able to enlarge 50,000 diameters with a separating power of only 0.003 micron. The separating power of the best optical microscope, using ordinary light, cannot be finer than 0.4 micron.

It is indeed not necessary to use such electronic super-microscopes, a far smaller instrument being easier to construct and being amply sufficient, because for false stellar images having diameters from 50 to 5 microns it would only be necessary to enlarge these images from 10 to 100 times in order to obtain photographic images on plate V with a diameter of 0.5 mm. If need be, enlargements from 100 to 1,000 times could be used, giving photographic images with a diameter of 5 mm.; these images would be affected in an insignificant way by all the known causes of photographic errors, such as the Eberhardt or other effects.

Such photographic images, as obtained by the present method, not being affected either by the slightest lack of definition, due to seeing, nor by the slightest error in guiding the telescope, will be perfect images similar to the theoretical images of double stars studied by Louis Roy in his memoir "Sur le diamètre apparent des disques stellaires et le pouvoir séparateur" (Annales de l'Observatoire astronomique de Toulouse, Tome XI, 1934).

For double stars, when the two discs are partially overlapping, the photographic images obtained on V will probably be similar to figure 2a, whereas when the two discs are separated, figure 2b might well represent them. By analyzing these images, using a sensitive photoelectric or thermoelectric photometer, the corresponding distribution curves of figure 3 could be obtained. To obtain these curves a very narrow slit of the photometer would scan the images of figure 2 in



Figs. 2 and 3—Images and curves to be obtained.

the direction of their greatest widths. As can be gathered from Louis Roy's memoir, the distance between the two maxima measured on different curves, similar to either of the curves of figure 3, obtained at the same moment with telescopes of various apertures for the same double star, is practically constant, and represents, on a proper scale, the angular distance between the two components; this is so, no matter whether the star's discs are separated or overlapping. This also appears to be true even if the two components differ widely in brightness.

Pending a practical study of the system, it may be interesting to compute in an approximate theoretical way, what lowest angular separation of visual double stars could be measured with the present method.

For a telescope having an aperture of 300 mm. with its object glass covered by a central screen, such as the screen C of figure 1, the angular diameter of the false image of a star is about 71″/300 = 0″.25, using a well-known formula. The photographic discs of the components of a double star, even if they greatly overlapped so that the length of the combined image would be about one-fifth greater than its width, would thus, by means of accurate photometric graphs, similar to those of figure 3, permit the measuring of an angular distance of the order of 0″.05. Such small angular distances have only been measured so far by the interferometer attached to the one-hundred-inch telescope of the Mount Wilson Observatory.

It is unnecessary to dwell here on the extraordinary possibilities of the present method and on its probable great accuracy in the case of wider or fainter pairs, which are impossible to be measured with the interferometer.

Though the method is so far on a purely theoretical basis, it may be pointed out that angular distances of the order of 0″.003 might possibly be measured by using the two-hundred-inch telescope of Mount Palomar.

July 18, 1940.

Second Communication

Further thought shows that the method can be improved. It has already been pointed out that the photoelectric cell M (fig. 1) should preferably be a modern high-vacuum cell with an electron multiplier. Such for instance is the Kubetski photoelectric multiplier (fig. 4), an improvement of the Slepian multiplier, which is described on page 340 of the book "Electron Optics, Theoretical and Practical" by L. M. Myers (London, Chapman and Hall, Ltd., 1939).

Whereas an ordinary potassium photoelectric cell gives an output current of 0.4 microampere per lumen, and a more sensitive caesium-oxide-silver cell (monatomic coating) gives an output current of 40 microamperes per lumen, the Kubetski photoelectric multiplier gives an output current in the order of 100 amperes per lumen!

Electron multiplication being already applied to the cell M, it may be pointed out that if such an electron multiplication is also applied to the output of the electron microscope F, the effective exposure

necessary to observe a double star can be reduced many thousand times.

In order to do this, instead of photographing the double star directly on the plate V and then analyzing this photograph by means of a photoelectric slit-microphotometer, in order to obtain a graph similar to that of figure 3, this graph should be obtained directly at the telescope by analyzing the electronic image of the double star formed at V.

An electronic image of about five millimetres in diameter may thus be formed at V, where there is no photographic plate. In the plane of V should be mounted an opaque screen with an open slit, say 0.05 mm. wide; this screen should be moved rapidly from left to

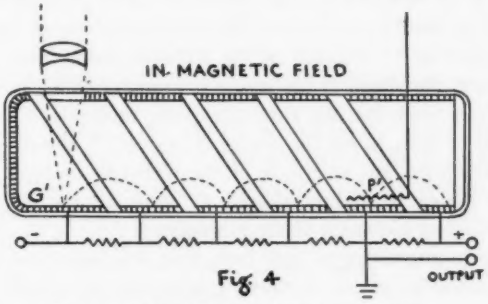


Fig. 4—Kubetski photoelectric multiplier.

right in order that the slit should scan the electronic image of the double star. Beyond V should be mounted another electronic microscope with its various parts corresponding to the various parts of the first electronic microscope, but symmetrically placed with respect to the plane of V, which, if the screen at V should be non-existent, should give an electronic image on a plate G′ (symmetrical to G) of practically the same size as the double star image at G. When the slit at V is being considered, however, only the electrons that pass through the slit will arrive at G′.

Now G′ can be made to coincide with the first electrode of a Kubetski multiplier (fig. 4) and the electronic current reaching G′ can thus give rise to an output current from the last electrode of the

multiplier which is at least one million times larger than itself. This output current acting on a sensitive galvanometer mirror, or acting on the electron pencil of a cathode ray oscillograph, can cause a very bright light spot to oscillate, for instance up and down, as it increases or decreases in intensity.

If this bright light-spot strikes a photographic plate which moves from left to right and back as the slit at V also moves from left to right and back, a graph similar to that of figure 3 will be obtained.

It is very important to note that in this last method the grid P (fig. 1) can be eliminated and replaced by a grid P′ (fig. 4) placed in front of one of the electrodes of the Kubetski multiplier of which G′ is the first electrode. The advantage of eliminating P and replacing it by P′ is considerable, because it might be difficult to design a grid P which would not in some way alter the shape of the electronic image formed at V, whereas in the Kubetski multiplier, whether P′ alters or not, the shape of the image is immaterial, as long as all the electrons can reach the last electrode of the multiplier.

As can be seen, when the seeing is perfect P′ allows all the electrons to reach the last electrode of the Kubetski multiplier, whereas when the seeing is slightly altered P′ stops all the electrons from reaching the last electrode of the multiplier.

It may be interesting to note here, that, the basic principles of the present method being now perfectly established, the writer is carrying on a minute study of all the details necessary to its execution. Correspondence has already been exchanged on the subject with the director of the National Observatory of Spain at Madrid, Don José Tinoco, and the method will be developed there, provided the writer may be permitted to enter Spain.

Le Houga (Gers), France,
August 12, 1940.

THE THIRTIETH ANNUAL MEETING OF THE A.A.V.S.O.

By David Rosebrugh

The thirtieth annual meeting of the American Association of Variable Star Observers was held at Harvard College Observatory, Cambridge, Massachusetts, October 19, 1940. It was fortunate for the association that our able president, Dr. Helen S. Hogg, of the David Dunlap Observatory, was able to be with us to conduct the meeting despite the present difficulty of crossing the border because of war conditions. As Mrs. Hogg is carrying on the work of Dr. Alice Farnsworth, as head of the Department of Astronomy, Mt. Holyoke College, South Hadley, Massachusetts, during the latter's absence on sabbatical leave, she was able to drive to the meeting with Miss Marjorie Williams of Smith College, at nearby Northampton.

The annual total of 45,646 observations submitted to the recorder, Mr. Leon Campbell, was somewhat less than for previous years, doubtless because our Canadian and British Empire observers and those in other countries disturbed by the war have not been able to work as efficiently as usual. However, the total observations submitted to headquarters since the organization of the society now exceed 800,000.

Mr. James G. Baker described one of his new flat field Schmidt cameras. He recommended amateurs to build an *f*.3 camera with a 6-inch crystallex correcting lens and a 10-inch Pyrex mirror, requiring a 36-inch tube and a 36-inch guide finder. Such a camera will give a flat field on the photographic film 2 inches square and a 10-minute exposure will show stars to the 12th magnitude without light fog.

Mr. Edward A. Halbach, chairman of the Auroral Committee, which is collaborating with the Cornell-National Geographic study, remarked that observers in the maritime and western provinces of Canada were urgently needed. The most promising field of study at present is continuous auroral arcs in the north. If the exact time of their appearance is noted it may be possible to determine whether an arc springs into existence, full fledged as a halo

around the north magnetic pole, or whether it moves progressively around the pole.

The Nova Scotia committee reported through its secretary, Mrs. E. S. Rademacher, that this programme is in full swing. Observers are urged to survey the entire sky each night by eye, and one or two smaller areas with binoculars. Report cards are available upon request.

Five members of the Milton Photographic Variable Star Bureau presented papers upon variable stars of more than ordinary interest. The strange light curves of these stars and their implications enlarged one's conception of the remarkable changes which these stars can undergo.

Dr. and Mrs. Harlow Shapley entertained approximately one hundred members and friends at a picnic lunch on the grounds of the Oak Ridge Observatory of Harvard, which is some 25 miles west of Cambridge, where the morning and afternoon sessions were held. The 36-inch Schmidt camera, housed in its own 25-foot dome, is practically ready for use, and such old friends as the 61-inch Wyeth reflector and the 16-inch Metcalf refracting camera were on display.

In the afternoon Dr. Donald H. Menzel showed movies of the new Harvard coronograph, installed at a height of over eleven thousand feet at Climax, Arizona. Pictures, apparently of the corona, taken on October 1, 1940, will be compared with those taken in South Africa at the total eclipse of the same day, to check the effectiveness of the coronograph. Moving pictures of prominences taken by Lyot of France with his original coronograph of this type showed matter apparently condensing from the upper photosphere, or lower corona and falling on to the sun along curved paths of magnetic or electrostatic force.

At Mrs. Hogg's request, Dr. Shapley acted as toastmaster at the annual banquet in the evening. He interspersed the remarks of other speakers with his own inimitable "Highlights of Astronomy for the Year." Principal among these were the studies by Dr. Lyman Spitzer of Princeton, who has shown that a filament of incandescent material pulled out of the sun by a collision or appulse with a passing star, would not condense into planets but would

expand into space. This disposes of the collision theory of the origin on the solar system and leaves us ignorant of its origin.

The secretary reported that, as usual, he had spent his brief vacation with his father, Dr. T. R. Rosebrugh, at Go Home Bay, Ontario. While there he had seen a splendid sunset followed by a beautiful evening. The poem which he wrote describing this scene was dedicated to "our Canadian friends" partly because it was written in Canada and partly because our 1940 Spring Meeting was held at Toronto. In the poem he had endeavoured to capture the true spirit of a Canadian summer evening.

THE EVENING OF AUGUST 7, 1940, AT GO HOME BAY, ON THE GEORGIAN BAY

Dedicated to our Canadian Friends

By One of the A.A.V.S.O. Observers

Observer, perhaps there may elapse
Many a moon and many a June
Ere another such fair night you see
So cherish this in your memory.

* * *

In purple vestments set the sun, behind a gnarled pine,
A cloud above it slowly turn'd, from golden to red wine.
The twilight bow rose in the east, the dusk began to fall,
A whippoorwill across the bay sounded his rhythmic call.

The four-day moon commenc'd to glow, above the wat'ry way
Which leads past many islands to the open Georgian Bay.
Up the moon track two paddlers pass, bright Spica guides their way,
Oh, for what more can young love ask, of Nature on display?

But Nature gives to such as these, and in the north soon dances
Aurora's arc with shimm'ring rays, before their entranc'd glances.
The stars shine down and they look up at Heaven's richest treasures,
The Northern Crown, the flying Swan, contribute to their pleasures.

In the far south the star clouds glow, around the Archer's uprais'd bow,
While in the north the Dipper shines, above the highest of the pines.
Upward through the auroral haze Perseus struggles through the rays.
With care we then survey the sky, never a nova meets our eye;
With glasses we search Perseus, no new star nor in Cepheus,
But a meteor cleaves the sky while the Northern Lights flame and die.

* * *

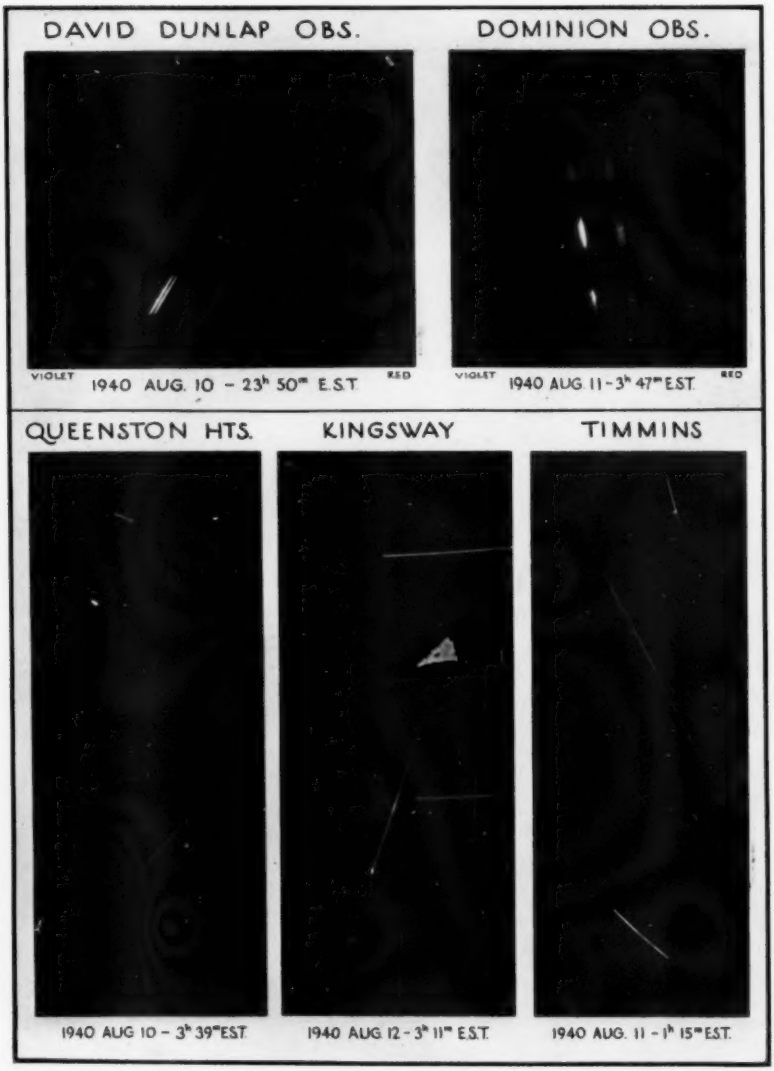
As with life, so all good things must end,
We turn to our bed, as to a friend,
And lay us down for a needed rest,
And dream of The Islands of the Blest.

The references in the last three lines of the fifth stanza, the secretary explained, were to his own personal nova search work.

Mr. Lewis J. Boss, the photographic Boswell of the association, showed coloured movies of the 1940 Spring Meeting at Toronto. The pictures of Dr. Chant, Dr. Young, Dr. Frank Hogg and Mrs. David Dunlap, and of the Union Jack, drew rounds of applause. At the close of the meeting regret was expressed by all that our Canadian members were not able to be present to see these movies because of war regulations about crossing the border.

18 Linden Rd.,
Poughkeepsie, N.Y.

D. W. Rosebrugh,
Secretary. A.A.V.S.O.



Spectra (above) and Direct Photographs (below) of five Perseid Meteors.

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

THE PERSEID METEOR SHOWER, 1940*

(with plate XXV)

It is gratifying to report that during August, 1940, as in the previous year, a very successful cooperative programme comprising the visual and photographic observation of the Perseid meteors was carried out in Canada. This was again made possible by the large number of amateur observers, both members of the Society and others, who took part so efficiently. Assistance in such work is one way in which the layman can render a real service to astronomical research and I hope that the making of Perseid observations in August will become a habit with all the more active members of our Society.

Work this year was planned for the five nights, August 9–14. Weather conditions throughout Ontario and Quebec were generally good during this period except for the night of August 12–13, which was pretty well obscured by clouds at all stations. The first quarter moon was present for an hour or two at the beginning of the observations but it was well west and since attention was centred on the radiant region in the majority of cases, the moon did not seriously influence the visual counts or the efficiency of the photographic work.

As in other years Miss Burland and Mr. Thomson organized the observing stations at the Dominion Observatory, Ottawa. Their groups made observations from two stations, the Observatory itself and Old Stittsville, almost twenty miles away. The account of these observations will be found in the following section but the summaries of rates and photographic exposures have been included in the general tables here for ease of comparison. Stations for visual and photographic work were again successfully operated by S. C. Brown at the Kingsway, Jack Grant at Orillia, A. H. Tiplin at Queenston Hts., E. R. Paterson at Camp Bois Franc, R. Vaughan at Timmins, and by Miss R. J. Northcott at Prince Albert. A number of other stations turned in good visual counts but were unlucky in the photographic observations. Excellent

*Communication of the David Dunlap Observatory, No. 7.

visual work was carried out by a group organized by C. R. Lounsbury at the Y.M.C.A. camp at Torrance, Ont.

At the Dunlap Observatory the writer again operated the multiple camera mounting used last year. This is equipped with a rotating shutter which covers the lenses of four spectrographs and two direct cameras. Twelve meteor photographs were secured with this instrument, three being spectra. Some other cameras were exposed at the Dunlap Observatory for short periods by those assisting with the visual work but no meteor photographs were secured in these attempts.

A complete list of all who assisted in the Perseid observations in 1940 follows. An asterisk indicates those who exposed cameras as well as making visual observations.

PERSEID OBSERVATION GROUPS—1940

1. *David Dunlap Observatory*—*E. W. Bullock, *F. C. Conley, M. Cunningham, *H. Dierlam, J. C. Duncan, Dr. S. H. Gould, J. Hare, *D. Mewhort, *P. M. Millman, D. Montmorency, A. L. Schawlow, Miss R. Schawlow, *G. Wilson Jr., J. Wright.
2. *Dominion Observatory, Ottawa*—*Miss M. S. Burland, Miss A. Fitzgerald, Miss D. Jolly, Miss J. MacLean, Miss M. McPherson, Miss F. Mentzel, E. Potvin, Miss K. Stokes, Miss N. Winges.

2a. *Old Stittsville, Ont.*—B. L. Bradley, D. Charbonneau, F. Cumming, P. Eastcott, L. Gardiner, J. Gillett, W. Krzyzewski, G. Lewis, S. Mott, *M. M. Thomson, Wm. Stranks.

3. *London, Ont.*—W. E. Ashdown, Miss Ashdown, Rev. W. G. Colgrove, Prof. H. R. Kingston, J. Middlebrook, Mr. and Mrs. C. J. Taylor.
4. *Kingsway, W. Toronto*—*S. C. Brown, H. L. Ward, Mrs. H. L. Ward.
5. *Orillia, Ont.*—*Jack Grant.
6. *Timmins, Ont.*—*S. Scott, *R. Vaughan.
7. *Queenston Heights, Ont.*—Miss K. Prebble, Miss V. Prebble, *A. H. Tiplin.
8. *Camp Bois Franc, Que.*—*E. R. Paterson.
9. *Torrance, Ont.*—C. R. Lounsbury, A. Milne, G. Shepherd, P. Teale, M. West.
10. *Guelph, Ont.*—*W. T. Patterson, B. R. Smith.
11. *Prince Albert, Ont.*—Miss E. Leach, *Miss R. J. Northcott.
12. *York Mills, Ont.*—Miss R. J. Northcott.
13. *St. Thomas, Ont.*—*O. Kilburn.
14. *Montreal, Que.*—De Lisle Garneau.
15. *Toronto, Ont.*—D. J. A. Byers, H. G. Byers.
16. *Hespeler, Ont.*—H. Seekins.
17. *Bridgewater, Mass.*—A. E. Cox.
18. *Monterey Park, Calif.*—*E. J. Arnold, S. Shea.
19. *St. Ephrem Stn., Que.*—L. Mathieu.

The number of meteors recorded visually was in all cases the total for the whole group, each meteor being counted only once. In the majority of cases these were divided by the observers into Perseids (P) and Non-Perseids (N). All meteors were plotted at most of the stations but in some cases, notably groups 2 and 2a, only the brighter meteors were plotted. The total numbers of meteors visually observed have been listed in Table I. Where a continuous watch of the sky was carried out for any appreciable time the total number of minutes observed has been given. In some cases the sky could only be watched occasionally, owing to time taken up with the cameras, and here the fifth column of the table has been left blank and the number of meteors observed should not be used for rates. The average number of observers active at any given time at a station has been given in the third column. In almost all cases there was a recorder in the group in addition to the number of observers listed.

The visual hourly rates, reduced to six observers, have been plotted in Figure 1 for those groups where the observations were carried out for some time without interruption and where the weather conditions were good. The numbers on the diagram are the group numbers. No correction for weather factor has been made in these plots. Each plotted point represents the observed rate for the full sixty minutes centred at the position of the plot. It is evident that the maximum occurred on the night of August 11–12. The rates for August 9–10 were about equivalent to those for August 13–14, or perhaps a little better. It is probable that August 12–13 was similar to August 10–11.

Accurate comparison with the shower in 1939 is difficult because in that year a very brilliant aurora appeared on August 11–12 and it was generally cloudy on August 12–13. Apparently the maximum was near August 12–13 in 1939 and shifted to August 11–12 this year, a result which was to have been expected since February 29, 1940, occurred between the two Perseid apparitions in question. In general I would conclude that somewhat fewer Perseids appeared in 1940 than in the previous year, though the rate observed by Tiplin at Queenston Heights on the maximum night of 1940 was quite high. Evidence for a drop in Perseid rate about 2 a.m. on August 11–12, 1940, is seen in all the plots for

that night. This is similar to drops in hourly rate noted at 2 a.m. on August 11–12 and at 1 a.m. on August 13–14 in 1939.

Magnitude distributions for the visual observations are given in Table II. A few more of the brightest meteors were recorded than in 1939 but nothing out of the ordinary was observed. The mean magnitude for the Perseids was very near 1.4 and for the Non-Perseids about 2.1. Magnitude estimates made under poor

TABLE I

VISUAL OBSERVATIONS OF THE PERSEIDS, 1940

Date	Group No.	Average No. of Observers	Observing Period (E.S.T.)	Total Minutes Observed	Meteors Observed P	Meteors Observed N	Weather Factor
Aug. 8–9.....	17	1	20.45–22.55	130	14	7	9
Aug. 9–10.....	1	4	23.00– 3.55	295	87	35	9
	2	4	22.30– 3.30	300	114		7
	2a	6	22.35– 3.55	320	164	96	10
	4	2	23.20– 1.50		17	3	9
	5	1	23.00– 4.00		8	0	10
	7	1	23.10– 4.00	290	40	31	7
	8	1	22.30–24.00		4	0	9
	14	1	22.00–23.30	90	5	1	8
	15	1	23.05–23.55	50	6	2	7
	17	1	20.55–23.50	120	10	4	9
	18	1	3.30– 5.00	90	9	6	10
	19	1	21.00–22.00	30	3	1	3
Aug. 10–11....	1	3	23.05– 4.10	305	167	67	10
	2	3	22.40– 3.50	310	130		7
	2a	6	22.20– 3.50	330	266	97	10
	4	2	23.00– 3.10		14	4	10
	5	1	21.00– 3.30		9	1	5
	6	1	23.10– 3.10	240	38	15	6
	8	1	24.00– 3.30		18	1	8
	12	1	22.30– 1.50	200	21	12	7
	14	1	21.45–23.25	100	9	2	8
	18	2	3.00– 5.40	140	26	14	10
	19	1	23.15– 3.45	250	40	7	10
Aug. 11–12....	1	2	22.30– 4.05	335	166	43	9
	2	5	22.30– 3.50	320	68		2
	2a	5	23.00– 4.00	300	94	49	2

TABLE I—*Continued*

Date	Group No.	Average No. of Observers	Observing Period (E.S.T.)	Total Minutes Observed	Meteors Observed P	N	Weather Factor
Aug. 11–12....	3	3	20.30– 1.00		37		2
	4	2	22.50– 3.40	290	69	6	10
	5	1	24.00– 3.30		8	1	7
	7	1	23.30– 4.10	280	182	31	8
	9	4	23.15– 2.30	190	83	25	7
	10	1	21.15–23.35	140	16	2	8
	11	2	23.10– 4.00	290	137	17	10
	13	1	23.15– 1.00	100	13	6	4
	14	1	22.20–24.00	100	10	0	6
	16	1	22.45–23.45	60	26	3	8
Aug. 12–13....	19	1	20.15–22.15	120	6	0	3
Aug. 13–14....	1	1	24.10– 3.50	220	9	4	4
	2	4	22.40– 4.00	320	113		8
	2a	6	22.20– 4.00	340	112	68	8
	5	1	1.00– 4.30		2	0	4
	10	1	21.55–22.55	60	3	0	4
	19	1	22.45– 2.15	180	18	3	10

Total meteors observed—3055.

TABLE II

MAGNITUDE DISTRIBUTIONS

Station		−4	−3	−2	−1	0	1	2	3	4	5	6	Total	Mean Mag.
D.D.O.....	P	1	3	14	36	58	64	103	83	25	14	1	402	1.5
	N	1			2	12	25	32	37	25	9	1	144	2.4
D.O.*.....	P+N		4	4	7	27	44	106	79	59	13		343	2.2
Stittsville* .	P	1	9	30	46	75	84	143	105	31			524	1.3
	N	1	1	9	7	22	36	70	80	20	1		247	1.9
Groups 4, 6, 10,11,12,18	P	2		9	10	26	103	119	58	9	1		337	1.5
	N				1	6	17	26	22	1			73	1.9

*Nights of Aug. 9–10, 10–11, 13–14 only.

weather conditions, and those of groups which observed only a few meteors, have not been included in Table II.

A summary of the photographic exposures and their results is given in Table III. A total of 50 meteor photographs was secured in an exposure time of 365 hours, that is one photograph for 7.3 hours' exposure as an overall average. In 1939 there were 43 meteor photographs secured in 341 hours or one photograph per 7.9 hours. Considering the direct photography alone one meteor was photographed for each 5.7 hours' exposure in 1940 and one for each 5.0 hours' exposure in 1939. This is, then, a fairly consistent expectancy in meteor photography for the five nights nearest the Perseid maximum. For the maximum night one finds a considerably higher expectancy, one meteor photographed in between three and four hours total exposure time. The expectancy of photographing spectra is much more uncertain but considering the two years together the value which I have given before still holds good, that is, the expectancy of securing a meteor spectrum of any kind is about one-fifth that for direct photography under similar conditions.

The 50 meteor photographs secured in 1940 were of 30 different meteors, all Perseids. Visual estimates for 26 of these meteors, made in most cases at the stations where they were photographed, gave the following magnitude distribution:—

Mag.	−3.5	−3	−2	−1.5	−1	−0.5	0	1	Total	Mean Mag.
Meteors	1	3	4	4	10	1	2	1	26	−1.4

Of the 30 meteors:

3 were photographed from 3 stations,
8 " " " 2 "

In 8 of the above 11 cases velocities will be available as well as photographically determined heights since photographs were secured with the rotating shutter. These results are all slightly better than in 1939.

In a discussion of the meteors photographed last year they were arbitrarily divided into four classes, viz.—short even trails less than 0.2 sec. duration; longer even trails; trails with one

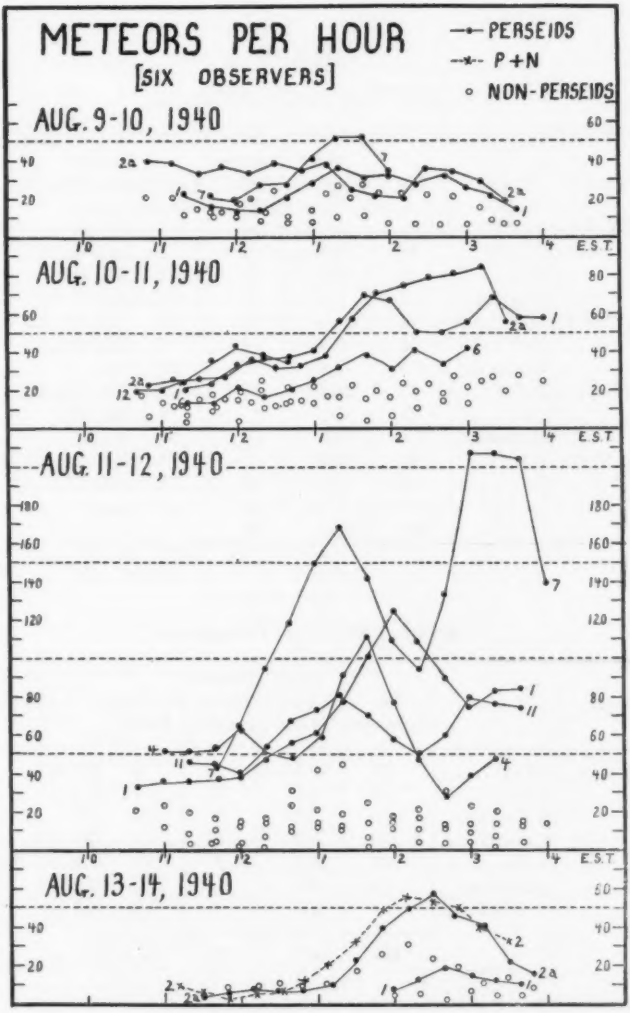


FIG. 1. Visual hourly rates for the Perseid Meteors, 1940.

TABLE III

PERSEIDS, 1940 (Spectrophotography)

Date	Station	No. Exposures	Total Exposure Time	Spectra Photographed	Weather Factor	Cameras
Aug. 9-10..	D.D.O. ..	16	19.5hrs.	1	9	4.5, 4.5, 4.5, 4.5, §
	D.O.....	16	9.8	1	7	3.8, 4.5, §
	Kingsway	3	2.4		9	4.5,
Aug. 10-11.	D.D.O. ..	16	21.1	1	10	4.5, 4.5, 4.5, 4.5, §
	D.O.....	16	9.4	2	7	3.8, 4.5, §
	Kingsway	4	3.8		10	4.5,
Aug. 11-12.	D.D.O. ..	16	22.5	1	9	4.5, 4.5, 4.5, 4.5, §
	D.O.....	10	5.1		2	3.8, 4.5, §
	Kingsway	6	4.7		10	4.5,
Aug. 13-14.	D.D.O. ..	16	19.6		4	4.5, 4.5, 4.5, 4.5, §
	D.O.....	18	9.3	2	8	3.8, 4.5, §
		137	**127.2**	**8**		

PERSEIDS, 1940 (Direct Photography)

Date	Station	No. Exposures	Total Exposure Time	Meteors Photographed	Weather Factor	Cameras
Aug. 9-10..	D.D.O.....,	22	19.3hrs.	1	9	2.0, 3.5, §
	D.O.....	8	6.1	1	7	6, 6,
	Stittsville....	7	3.7	2	10	4.5,
	Kingsway...	12	5.0	1	9	3.5, 6.3,
	Orillia.....	42	20.8	2	10	1.9, 4.5, 6.3, 8,
	Queenston...	14	9.4	4	7	2.9, 3.5,
	C. Bois Franc	4	2.0		9	4.5,
		109	**66.3**	**11**		

TABLE III—*Continued*

Date	Station	No. Exposures	Total Exposure Time	Meteors Photographed	Weather Factor	Cameras
Aug. 10-11.	D.D.O.....	16	10.5hrs.	4	10	2.0, 3.5, §
	D.O.....	14	8.8		7	6, 7.9,
	Stittsville....	16	8.9		10	4.5, 4.5,
	Kingsway...	14	7.7	1	10	3.5, 6.3,
	Orillia.....	39	20.5	2	5	1.9, 4.5, 6.3, 8,
	Timmins....	17	7.2	2	8	3.5, 4.5,
	C. Bois Franc	6	3.0	3	9	4.5,
	Monterey Pk.	17	4.3		10	4.0, 4.0,
		139	**70.9**	**12**		
Aug. 11-12.	D.D.O.....	19	14.2	4	9	2.0, 3.5, §, 8,
	D.O.....	1	0.6		2	7.9,
	Stittsville....	12	5.2		2	4.5, 4.5,
	Kingsway...	22	9.2	5	10	3.5, 6.3,
	Orillia.....	46	21.0		7	1.9, 4.5, 6.3, 8,
	Queenston...	14	9.0	6	9	2.9, 3.5,
	Guelph.....	5	2.4		7	8,
	Prince Albert	5	4.5	4	10	4.5,
	St. Thomas..	1	0.8		4	
		125	**66.9**	**19**		
Aug. 12-13.	Orillia.....	3	0.9		2	4.5, 6.3, 8,
Aug. 13-14.	D.D.O.....	16	9.7		4	2.0, 3.5, §
	D.O.....	4	2.2		8	7.9,
	Stittsville....	13	8.0		8	4.5, 4.5,
	Orillia.....	27	13.2		4	1.9, 4.5, 6.3, 8,
		60	**33.1**	**0**		

SUMMARY

Aug. 9-14..	Spectro-photography	137	127hrs.	8		
Aug. 9-14..	Direct photography	436	238	42		
		573	**365**	**50**		

§Rotating Shutter used.

terminal burst; and trails with three or more terminal bursts. Strangely enough this year, out of the thirty meteors, there were none in the fourth group. The examination of the photographs and a comparison with the visual observations gave the following results:—

	No. Meteors	Mean Vis. Mag.	Mean Train Dur.
1. Very short even trails (dur. 0.2 sec. or less)	7	−1.1	0.5 sec.
2. Longer even trails	17	−1.1	1.8
3. Trails with single short, bright terminal burst	6	−2.5	3.6

As was found in 1939 the meteors with definite terminal bursts averaged over a magnitude brighter than those with even trails. The 9 direct trails photographed at the Dunlap Observatory with the rotating shutter had durations ranging from 0.2 to 0.4 seconds with a mean value of 0.3 seconds. As a whole the meteors photographed this year seem, from a study of the plates, to be fainter and less striking than those secured in 1939 in spite of the brighter visual estimates of 1940.

The eight spectra obtained were all secured on fast panchromatic film and were of six different meteors, three observed at the Dunlap Observatory and three at the Dominion Observatory, Ottawa. Of the former, two are very faint but the third contains one bright burst (see Plate XXV) and shows good definition right into the red. Over thirty bright lines have been measured in this spectrum and it confirms satisfactorily the identification of elements found in the spectrum secured in 1939. A complete discussion will be published later. Of the five spectra taken at Ottawa, two were on exposures where the meteor crossed the field parallel to the dispersion and hence show practically no detail. Photographs of these same meteors, however, were secured on cameras with the prisms placed so that the dispersion was approximately perpendicular to the flight of the meteor. One of these has also been reproduced in Plate XXV. Its correspondence with the Dunlap Observatory spectrum is at once evident. In fact all three Ottawa spectra confirm the general character of the two Dunlap Observatory spectra which show good detail down into the red. In the

Ottawa spectrum reproduced in Plate XXV it will be noticed that the meteor has become definitely bluer toward the end of its path, a behaviour followed in both spectra reproduced in the 1939 Perseid report.

In closing I sincerely thank the many observers who contributed to the success of this program. Once more it has been demonstrated that very valuable photographic as well as visual results may be secured if careful cooperation is maintained among the various groups taking part. The interest in meteor photography which is evidenced by the above report should not be allowed to wane.

PETER M. MILLMAN.

David Dunlap Observatory,
Richmond Hill, Ont.

PERSEID METEOR OBSERVATIONS AT OTTAWA, AUGUST, 1940

By MALCOLM M. THOMSON and MIRIAM S. BURLAND

Thank you very much! That was swell! Let us know when you are going to observe again! Such were the expressions of farewell as one after another of the Ottawa observers were delivered to their homes after the last night of the Perseid programme this summer. Personal pleasure and scientific endeavour were both served.

As in previous years, so again this summer two groups were organized. One observed from the roof of the Dominion Observatory, while the other was located at a point just west of Old Stittsville, about 17 miles straight line from the Observatory. This second location was made available through the courtesy of Mr. Herb Moore. He at first thought it was the intention to erect some kind of observing tower from which a look-out might be kept for enemy air raiders. The study of meteors, or shooting stars, was something new. He and his neighbours were quite pleased to visit the tent in the evening, look at the moon through field glasses for the first time, and hear some of the interesting facts of astronomy.

The Stittsville group was equipped with field glasses, two cameras of speed f/4.5, and observing charts and recliners for six observers and one recorder. Ideally placed far from any highway or power line, the location proved excellent for visual work. Rain fell on one of the five nights, Monday, August 12–13, and the previous night was partly blanketed with clouds. The other three nights provided conditions which varied from medium to first rate, the total number of meteors timed being 946. So far as possible, the brightest of these were traced on star charts. The two cameras at Old Stittsville were exposed for a total of $25^h\ 48^m$ with two trails as the result.

At Ottawa, the group observed again from the roof of the Dominion Observatory. In addition, the greater part of the camera equipment was operated here under the personal supervision of Miss M. S. Burland. Two cameras with prism and rotating shutter attachments, and three others with no attachments, completed the photographic array. The rotating shutter covered the lenses ten times per second. One direct and five spectrum photographs were obtained, there being $17^h\ 33^m$ of direct and $33^h\ 39^m$ of spectrum-shutter exposure time. This is the largest number of meteor spectra obtained by the Ottawa observers since the meteor programme was adopted here five years ago. Weather conditions at Ottawa parallelled those at Old Stittsville except for the disadvantage of city lights and perhaps more haze. With smaller observing groups, a total of only 425 meteors was timed.

Thanks are due to Mr. Wm. Hill, Optometrist, for the loan of two prisms, and to Miss L. Johnson and Mr. J. Cole for the loan of cameras.

Observers at Old Stittsville: Messrs. B. L. Bradley, Don Charbonneau, Franklin Cumming, Peter Eastcott, Lorne Gardiner, Jack Gillett, Walter Krzyzewski, Gerald Lewis, Stanley Mott, William Stranks, and M. M. Thomson.

Observers at Ottawa: Misses Ann Fitzgerald, Dorothy Jolly, Jean MacLean, Margaret McPherson, Florence Mentzel, Kathleen Stokes, Norma Winges, Miriam S. Burland, and Mr. Emile Potvin.

Dominion Observatory,
Ottawa, Ont.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Ball Lightning, Ignis Fatuus or—What?

Records of the phenomena of ball lightning run back some centuries and it is still a great mystery. But observations made by many intelligent persons, some of them being trained scientific workers, leave hardly a doubt of the objective reality of what was seen. Perhaps the most discriminating review of the subject is that prepared by W. J. Humphreys and printed in the *Proceedings of the American Philosophical Society*, vol. 76, p. 613, 1936. Dr. Humphreys has long been a member of the U.S. Weather Bureau and has made many distinguished contributions to science, including his "Physics of the Air" (3rd ed. 1940). In 1924 and again 1931 Dr. Humphreys made a request for observations of ball lightning and he received 280 replies. Some of these were by well-known physicists. The observations described were so varied that he had no reasonable explanation to offer in many of the cases.

The phenomenon is usually related to an ordinary thunderstorm, but the observation of a luminous ball in motion is reported in other circumstances. A letter received by the present writer from a former student of his, Mr. Charles F. Tilbury of Galt, Ont., contains the following remarkable statement:

While visiting on Monday, Nov. 11, 1940, I heard this strange story:

"On Sunday night, Nov. 10, or rather Monday morning, since it was 12.15 a.m., Mr. and Mrs. Weaver, who live on the Governor's Road, near London, Ont., were driving home, in fact they were quite near their own driveway. Suddenly they noticed, for both saw it, coming towards them from the west, at about a quarter of a mile distant, what appeared to be a car on fire. They watched it as it came down the road to meet them and soon found that this fiery-red mass, roundish in shape, the height and width of a car, with a purplish tinge to it, was no car on fire but a large 'fire-ball'.

"They drove into their driveway and from this point of vantage they watched this phenomenon as it seemed to lightly drift or bounce along the surface of the road. When this ball of fire arrived at about a hundred yards from them it suddenly shot up into the air to a height of approximately fifty feet and while in the air, arms or streamers of light shot out from the centre of it, sideways. Down it came to the road and then once more it rose suddenly

to the same height. Finally it descended and as it hit the surface of the road it broke up and disappeared like a flash.

"Mr. Weaver walked to the place later where this 'fire-ball' seemed to have hit the road twice and found a little white precipitate somewhat like slaked lime, although, as he says, that may easily have been there previously.

"As a sequel to this strange experience, when the light had ceased they observed a man walking along the road towards them, with his back to the phenomenon. Apparently there could have been little reflection for when questioned he stated that he had seen nothing."

Weather Conditions. Rain had fallen heavily all Saturday night and most of Sunday, the 10th. In the late evening the rain ceased and a very warm, strong wind, unusual for this time of the year, blew from the S.S.W.

Location of Event. On a stone road, well-drained, crossing fairly high land. Not far from the road is the valley of a stream. On both sides of the road there are open fields and some buildings and trees.

Would this be of the nature of "ignis fatuus"? although I have never heard of such a phenomenon ever being found in this district before. Fairly high land, with a valley not far distant—Why not in the valley?

Later. A copy of the above report was sent to Dr. Humphreys at Washington, D.C., and he offers the following novel solution: "It is my guess that the spooky ball of fire was an owl, hunting for something to eat, after coming out of a decaying hollow tree where he had gotten covered with fox-fire fungus. This interesting case is at least the fifth of its kind that has come to my attention."

Any other suggestions?

C. A. C.

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p. 233, l. 1. June 14 should be June 4. It is given correctly on p. 207.
p. 318, l. 2 from bot. Bathurst should be Dufferin.
p. 376. The title of Figure 1 should be: Distribution of Measured Deviations ($\Delta\alpha$).

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